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The photomultiplier tube calibration system of the MicroBooNE experiment

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ABSTRACT: This tech note summarise the installation, design and first tests of the LED flasher system used to calibrate the PMT system in the MicroBooNE experiment.

KEYWORDS: Neutrino detectors,Time projection chambers,Detector alignment and calibration methods (lasers, sources, particle-beams), Detector design and construction technologies and materials.

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Contents

MicroBooNE uses 32 8 " Hamamatsu PMT's, covered with tetraphenyl butadiene (TPB) coated front plates to detect the UV scintillation light in light argon. For R&D purposes four 2 " PMT's connected to TPB coated scintillation planes are installed in the detector. Each of the PMT's was characterised before installation in warm and cold. After installation in the MicroBooNE detector, they are inaccessible, thus to calibrate the PMT system installed for the MicroBooNE experiment, a dedicated LED flasher system was installed [1]. In Figure 1 we show a sketch of the system; optical fibers connected to each of the PMT's and allow to send single-photon pulses issued from a LED which is controlled by a pulser board. Equal length fibers of 15.5 m connect each PMT with the LED flasher feedthrough. All LED's can be pulsed either individually or simultaneously, thus

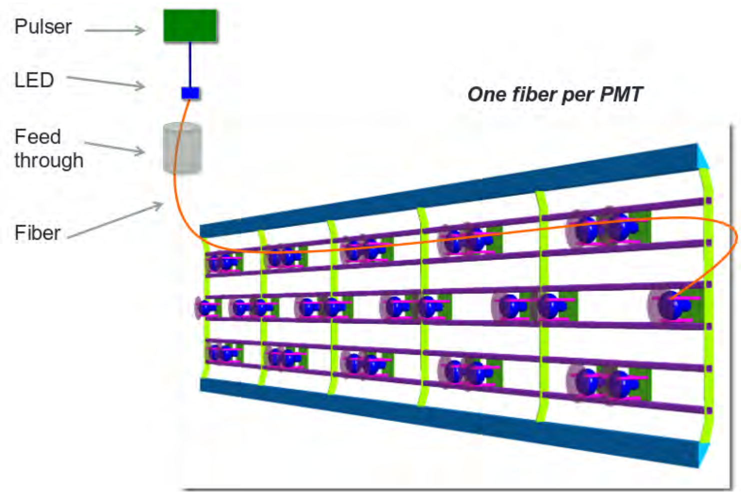


Figure 1. Sketch of the PMT flasher system. Optical fibers connect the PMT's to a LED pulser board for single-photon calibration.

Figure 2. The flange for the fiber feed through had to be placed in the center of the PMT feed through., the only available space is indicated in red.

the PMTs can be timed in to one another with a precision of a few hundred picoseconds. Using the beam trigger, the system can be timed into the TPC readout to allow the filtering of cosmic tracks by matching their scintillation light pulse with the deposited charge recorded in the TPC.

The LED flasher was used to test the PMT's after installation and will be used for calibration after the detector is filled with liquid argon. A custom-made flange allows to couple the fibers into the detector, its position on the PMT feed through is shown in Figure 2. The size constraint on top of the PMT flange allowed only for a CF2 3/4" sized opening.

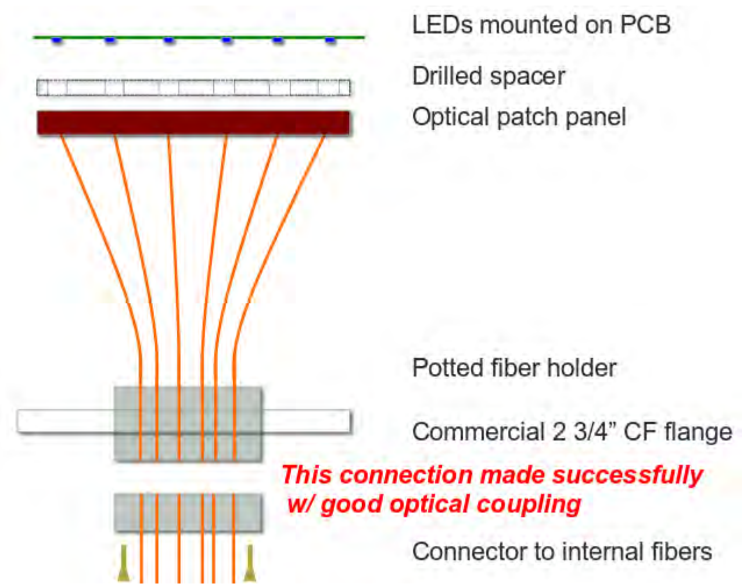


Figure 3. Sketch of the LED flasher feed through design. The fiber bundle connects to the feed through similar to a standard SMA connector. Outside the flange the fibers are spread onto a patch panel which couples to the LED's.

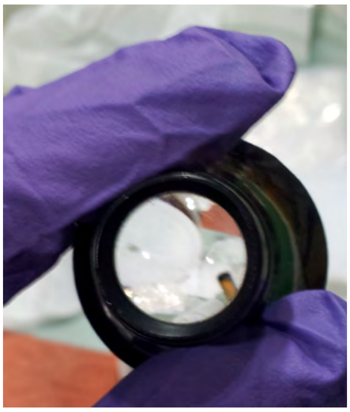


Figure 4. Detail image of the fiber edge after the cutting procedure.

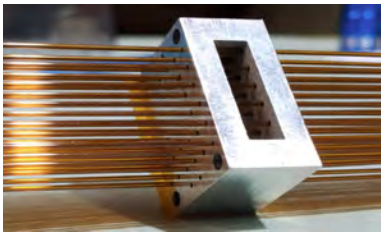


Figure 5. Fiber connector during assebmly.

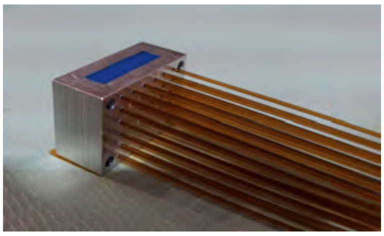


Figure 6. Long fiber connector after StyCast application.

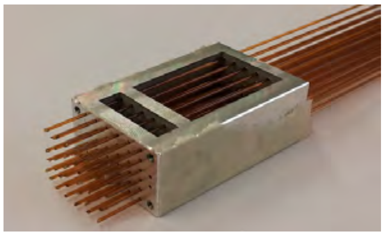


Figure 7. Short fiber connector during assembly.

In Figure 3 is shown a sketch of the LED flasher feed through design. The fibers coming from the PMT's are bundled and connect to the feed through and another fiber bundle. Outside the flange shorter fibers are spread onto a patch panel which couples to the LED's. This separation was required for installation purposes to avoid damage of the delicate fibers. Additionally one could test the vacuum tightness under cryogenic conditions for the CF feed through. The flange was also tested with 45 psi overpressure. The fibers are bundled into a block to form a 6×6 matrix with a size of $1.5\,\mathrm{cm} \times 1.5\,\mathrm{cm}$ to fit the CF2 3/4" sized opening. The long fiber ends are cut with a special fiber cutter, the CF flange has a diamond polish on both sides. This allows an optical coupling of a similar quality to that in a standard optical SMA connector. Shown in Figure 5 and 6 is the connector block of the long fibers. All fibers were inserted before their ends were cut and then held in place during the application of the StyCast, we used the Arathene CW 5620 blue with the Arathene HY 5610 hardener. The malleable StyCast was used to secure the fiber ends without damaging the fibers through thermal expansion and contraction.

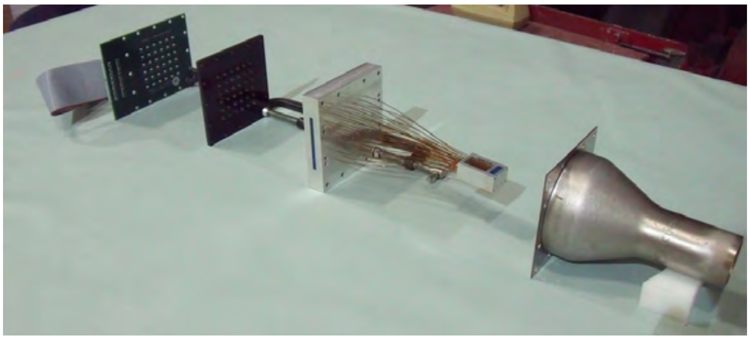


Figure 8. LED flasher feed through components, on the left the LED board and the spacer, in the middle the large patch panels with the conner bundle wight he fibers, on the right the CF seal with the light tight housing.

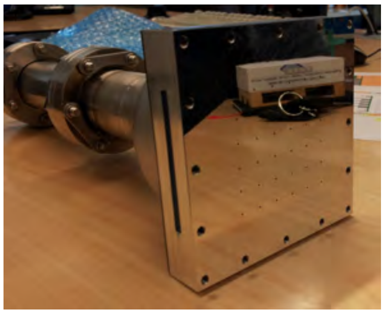
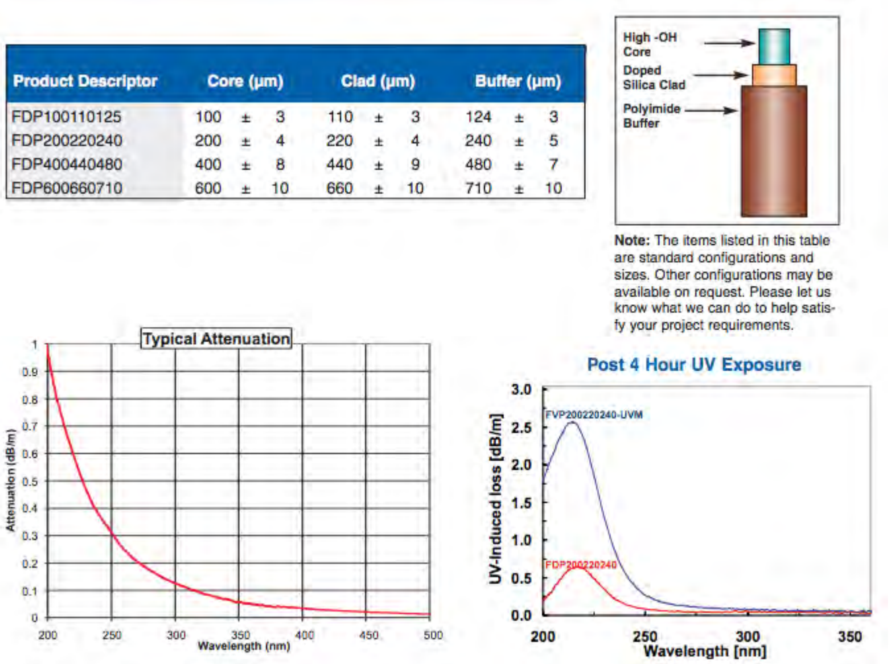


Figure 9. Assembled feed through during the vacuum test showing the polished patch panel surface.



Product Descriptor	Core (µm)	Clad (µm)	Buffer (µm)
FDP100110125	100 ± 3	110 ± 3	124 ± 3
FDP200220240	200 ± 4	220 ± 4	240 ± 5
FDP400440480	400 ± 8	440 ± 9	480 ± 7
FDP600660710	600 ± 10	660 ± 10	710 ± 10

Figure 10. The specification by MOLEX for the 600 μm core fiber Image is taken from MOLEX.com.

In Figure 7 is the connector for the short fibers of the CF feed through. The small opening in the block is used to add StyCast for fixing the fiber position, the larger hole is used for the StyCast that seals the opening in the CF flange and the fibers. In Figure 8 is shown an exploded view of the CF feed through parts, on the left is the the LED board and the spacer, in the middle the large patch panels with the conner bundle wight he fibers, on the right the CF seal with the light tight housing. After the assembly the patch panel surface and the fiber connector were diamond polished to optimise the optical coupling the the fibers, Shown in Figure 9 is the polished surface of the patch panel.

The fiber core has a size of 600 μm, with a cladding of 30 μm and an additional buffer layer

Figure 11. Fiber mounted in front of a PMT in the detector before the attachment of the TPB coated plate.

Figure 12. Fiber mounts, a custom made holder connects to the TPB holder to point the fiber to the PMT.

Figure 13. Fiber mount with nylon-tipped screw.

of 25 μm. Each fiber has a length of 15.5 m to connect from the flange to the PMT. The attenuation at 800nm is less 4.0 dB/km, which is the wavelength of the LED's [3]. The full details are given in Figure 10. The fibers are routed along the PMT frame inside the detector, and held in place by teflon ties, with strain relief wherever possible. Since they have no outer jackets, these fibers are very fragile so care was taken during installation not to snag or kink any of the fibers. While the fibers allow easy bends when the buffer layer is undamaged, they instantaneously snap apart if this layer get scratched. The avoid damages after installation, each contact point of the fibers along the frame was covered by teflon netting. Similar fibers were repeatedly cryo cycled in different test stands and do not show any signficant fatigue or observable purity problems [4].

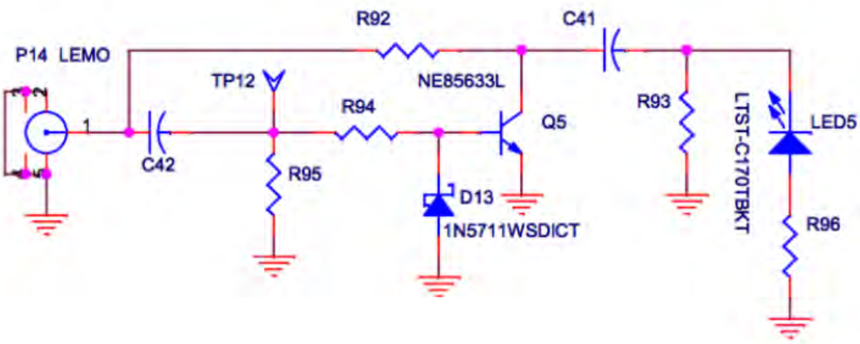


Figure 14. Single LED line diagram for the LED flasher system.

The fiber are mounted to individual PMT assemblies; the fiber is held in place in a aluminium standoff with a nylon-tipped set screw, as shown in Figure 11 with a PMT mount attached the the PMT's TPB plate holder. in Figure 12 is shown the individual fiber holders, a detailed view of the actual holder is shown in Figure 13. The fiber holder is attached to a threaded rod which holds the TPB plate away from the magnetic shield via two round panduit clamps crimped together onto a 1 mm threaded rod. The panduit clamp is held in place on the threaded rod by two nuts and a lock washer. This mounting system was developed and tested in different test stands at

Fermilab. The fiber end points at the PMT photocathode from underneath the wavelength shifting plate, approximately 2 cm from the surface of the tube.

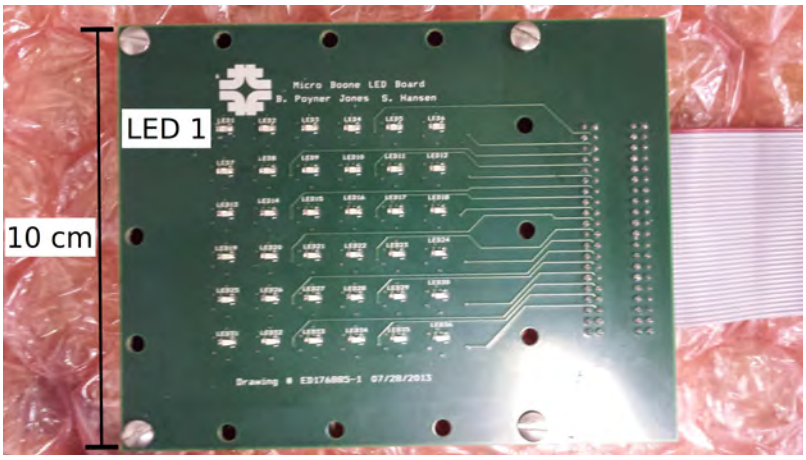


Figure 15. Image of the LED board with the 400 nm LED's shown [2].

The driving electronics for the LEDs are based on a system which has been used to pulse LED's at another test stand, in Figure 14 is the single LED line diagram shown. By sending a 1 ns pulse a capacitor is discharged, its pulse height is determined by the applied DC bias voltage. To allow the pulsing of 36 LED's, the system is made with two PCB cards, mounted directly onto the feed through. Both cards are connected by short 37 pin keyed ribbon cables[1] The card directly mounted to the patch panel is referred as LED board, shown in Figure 15, it houses 36 400 nm surface mount LED's spaced in a 6×6 grid with 1 cm spacing which align with fibers. To accommodate the LED's, a plastic spacer with 3 mm wide holes is mounted in between the board and the patch panel. On the reverse side of the board are the LED driver circuits, the PCB print is shown in Figure 29, Figure 30 shows the schematic. The board is covered by a black plastic housing screwed down onto the top side. 16 screws allow a tight seal, additional optical silicon will be used to ensure the light tightness.

A further PCB board is required to drive the LEDs, shown in Figure 16 and referred as Driver board. The board controls the brightness and timing of LED pulsing, as well as all communication of the system with the DAQ. The PCB print is shown in Figure 31, Figure 32 shows the schematic. The board is connected to the LED board by 37 pin ribbon connector for 36 LED's and the ground. The board receives its 8 V operating voltage from a DC low voltage power supply of the PMT rack, the intensity of the LED is set by the offset voltages on each pin of the ribbon, it can be chosen to be between 0 and 12V, programmable via USB. A flash memory on the board with one-hundred thousand read/write cycles allows to store the operating parameters. A USB connection allows a remote access for modifying the settings in the future.

The board is instructed to pulse via one of two LEMO cables, which accept logic pulses. One is the TTL burst mode, which initiates a simultaneous 1 ns pulse on every LED channel. This mode will be used for timing calibration. The second input called TTL Seq initiates a sequence where each LED is pulsed in succession, from 1 to 36, with a 200 ns gap. This allows to establish

[1]The board design was done by Sten Hansen at Fermilab.

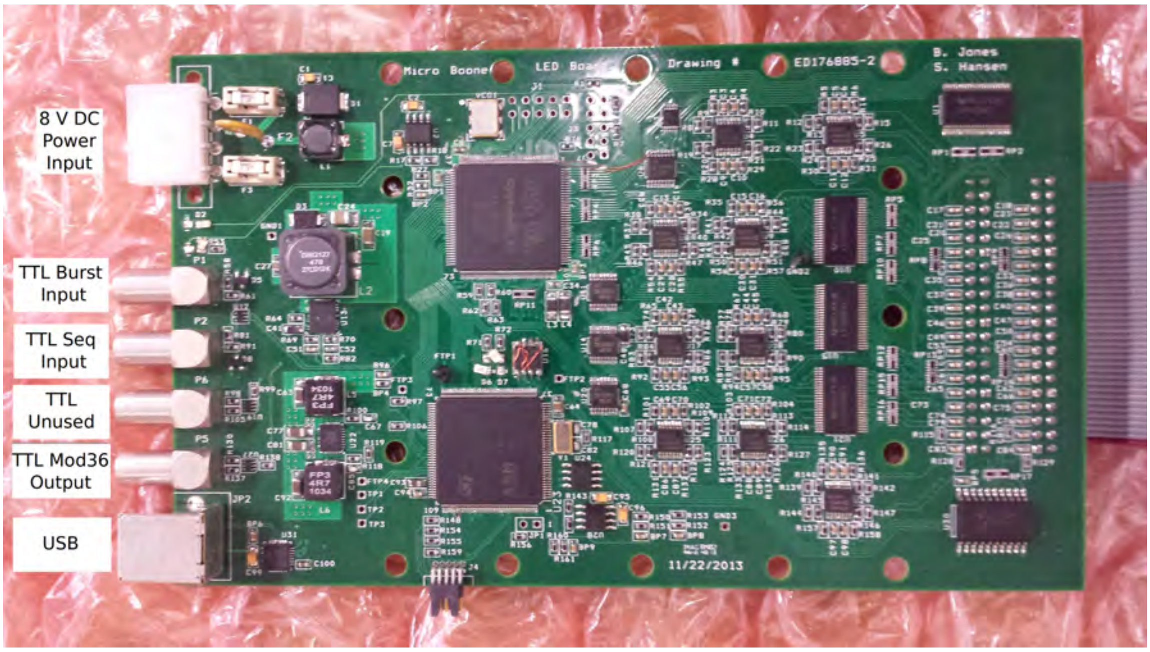


Figure 16. board closeup labeled [2].

PMT cross talk measurements and adjust the individual gain settings of the PMT's. The board is able to provide a trigger output, one LEMO connection is used for each individual LED pulse, while the second output refers to the pulse of the 'first' LED in the sequence mode. With this design choice, the board fires only when it receives an external command, this allows to operate in anti-coincidence to the neutrino events issued with the Booster Neutrino beam gate signal. and minimises the risk of interfering with real data taking.

This board and a second black plastic cover to protect the board are screwed down onto the top of the previously described stack. With this scheme, everything below the optical patch panel is permanently attached to the detector, whereas everything above including spacer, LED board, plastic cover, LED control board and plastic cover can be replaced after detector installation.

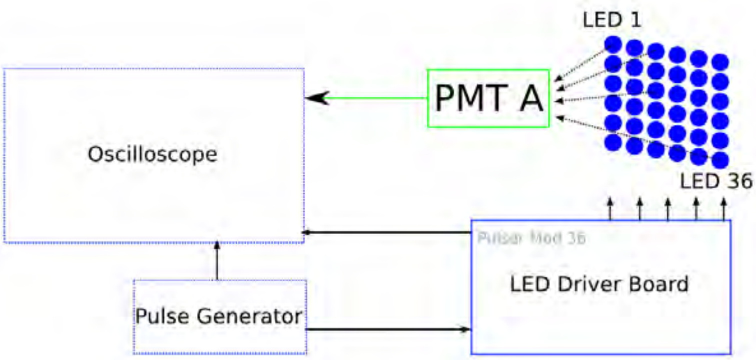


Figure 17. Test setup for LED time delay measurements [2].

The LED board was characterised and calibrated [2]. The time delay between the rising edge of the incoming LEMO TTL Seq signal and the rising edge of the PMT signal was measured. The setup for this measurement is shown in Figure 17, a PMT facing the flasher board is housed in a light thigh box; the bias voltage of the LED is set to zero and slowly raised for each LED till a signal can be observed. When correcting for effects of the experimental setup, the average time delay was $125.65 \pm 0.11 ns$. The delay times for each individual LED are shown in the left in Figure 18. The time delay variation among the LED's is $0.68 ns$, this is larger than the statistical uncertainty of individual LED's. The right of Figure 18 visualises the time delay for the 6×6 LED grid, no clear systematic shift of the time delay is visible.

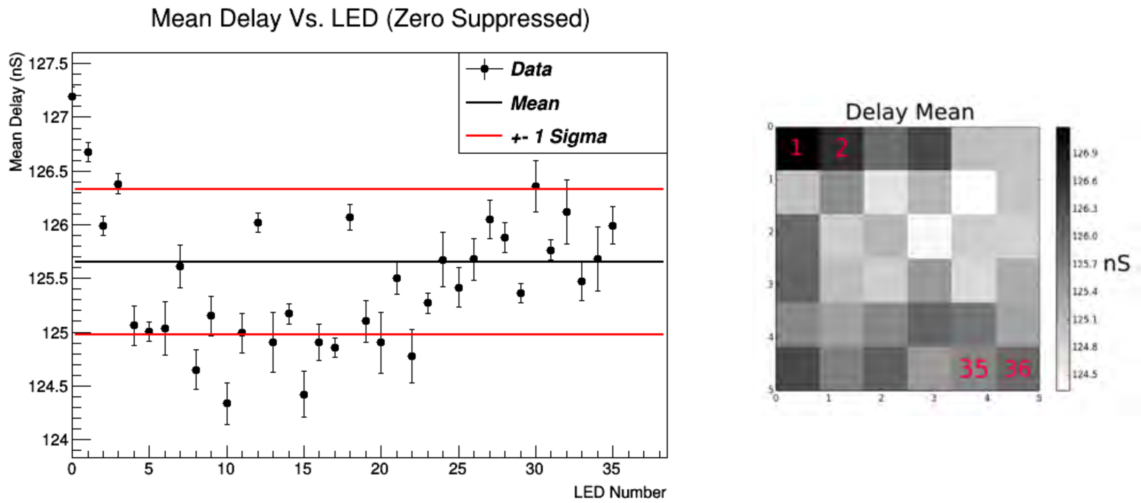


Figure 18. On the left is the mean time delay by LED. In black is the mean of the data points with its statistical error. The red band shows one standard deviation around the common mean value. On the right is the time delay plotted in the 6×6 grid of the LED board, no clear systematic effect is obvious[2].

The second timing parameter that needed to be calibrated was the time delay between the pulses in the sequential mode. This mode has a time-out, e.g. if the pulse frequency is too low, the sequence restarts with the first LED. Additionally there is the potential danger of pulsing the LED's too fast; a 1 ns pulse on the bias voltage signal is used to flash the LED, if the pulse repeats to quickly, the set voltage bias will not be reached and no light will be emitted by the LED. The test setup is shown in Figure 19.

The flasher system in operates stable between 1kHz and 10MHz. Lower frequency were tested by hand and it was found that the expected timeout is correctly set to between 10 and 15 seconds. At high frequency the LED output intensity starts to drop, as expected, and shown in Figure 20 for a sampling of one LED. The exponential fit describes the voltage as a function of time in an RC circuit during charging, which is exactly the physics of this circuit.

References

[1] B. Jones, T. Strauss, *Proposal to Install a PMT Flasher System in MicroBooNE*, MicroBooNE Doc-DB 2672. http://microboone-docdb.fnal.gov:8080/cgi-bin/RetrieveFile?docid=2672

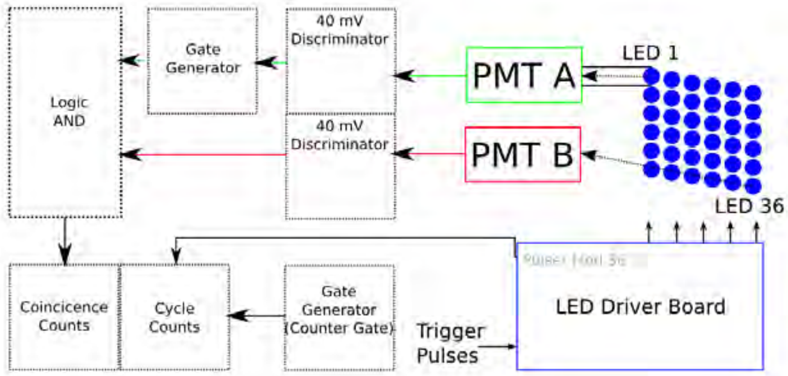


Figure 19. The setup for the frequency dependence of the LED board. PMT A is masked to LED1 with black vinyl [2].

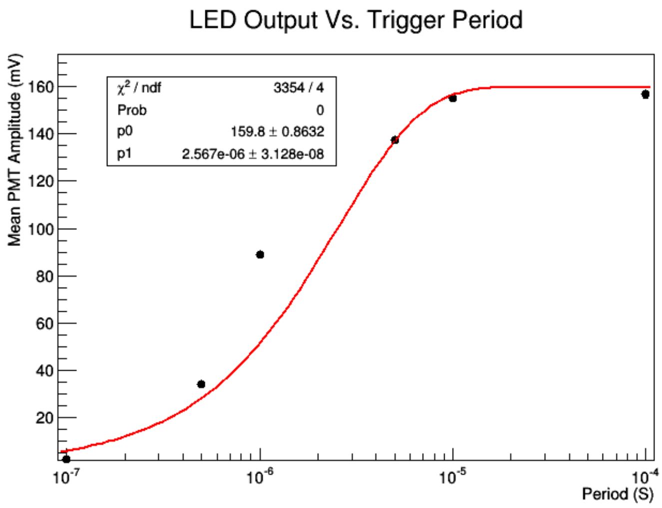


Figure 20. LED amplitude as a function of pulse period [2].

[2] A. Moss, *Technote: Characterization of the LED Flasher Calibration System for the MicroBooNE PMT Array*, MicroBooNE Doc-DB 3681. http://microboone-docdb.fnal.gov:8080/cgi-bin/RetrieveFile?docid=3681

[3] Spec-Sheet, Molex Polymicro fibers, www.molex.com/polymicro/opticalfibers.html

[4] B. Rebel, et. al, *Results from the Fermilab Materials Test Stand and Status of the Liquid Argon Purity Demonstrator*, 2011 J. Phys.: Conf. Ser. 308 012023

A. Technical drawings of the LED flasher feedthrough

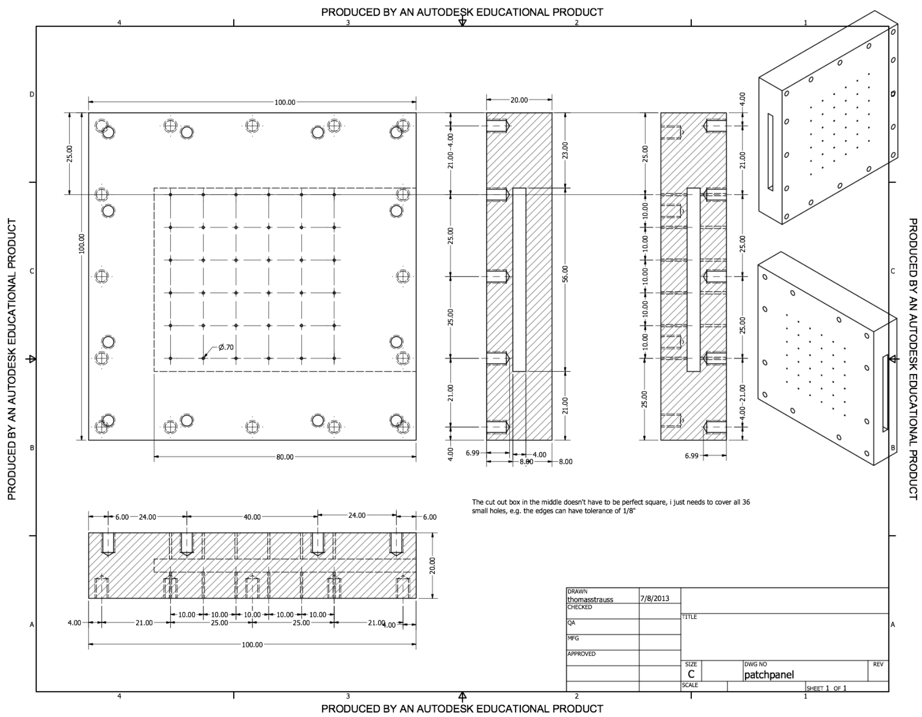


Figure 21. OpticalPatchPanel.

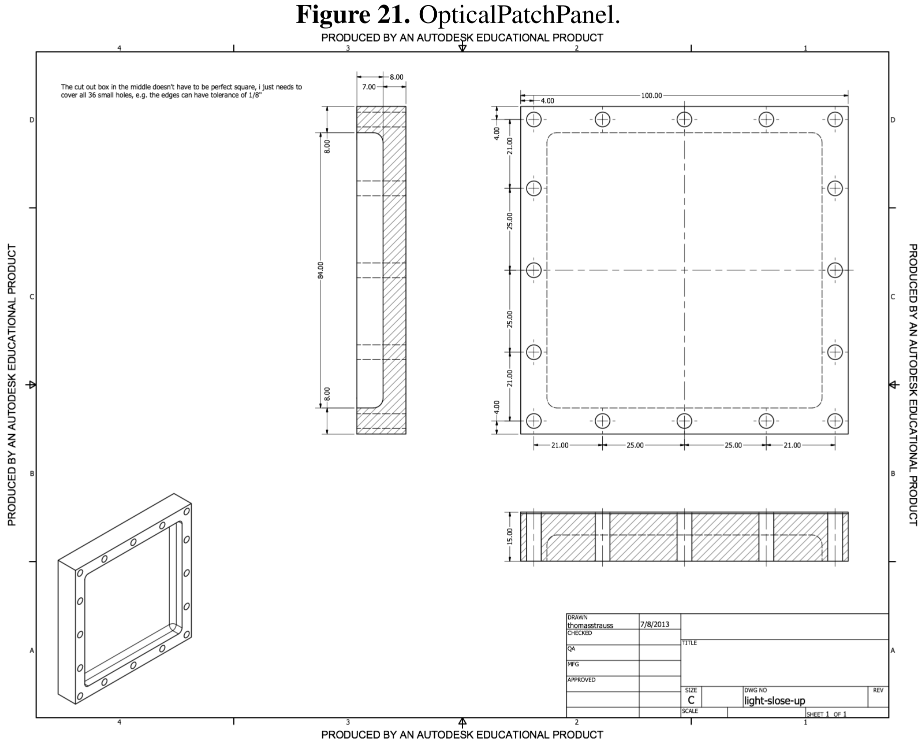


Figure 22. PCBCover.

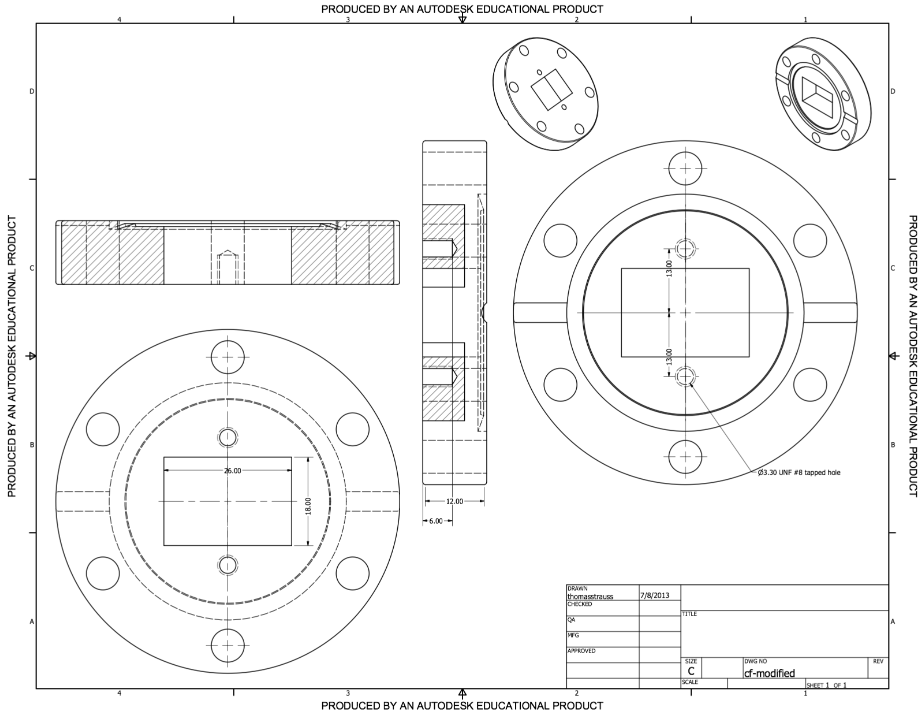


Figure 23. ModifiedCFFlange.

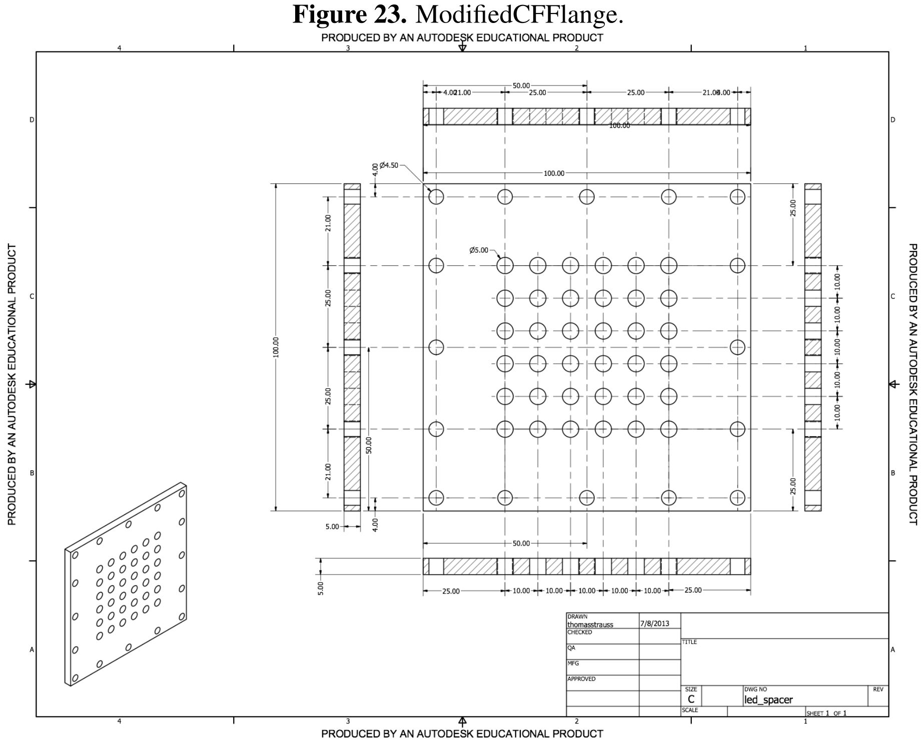


Figure 24. LEDSpacer.

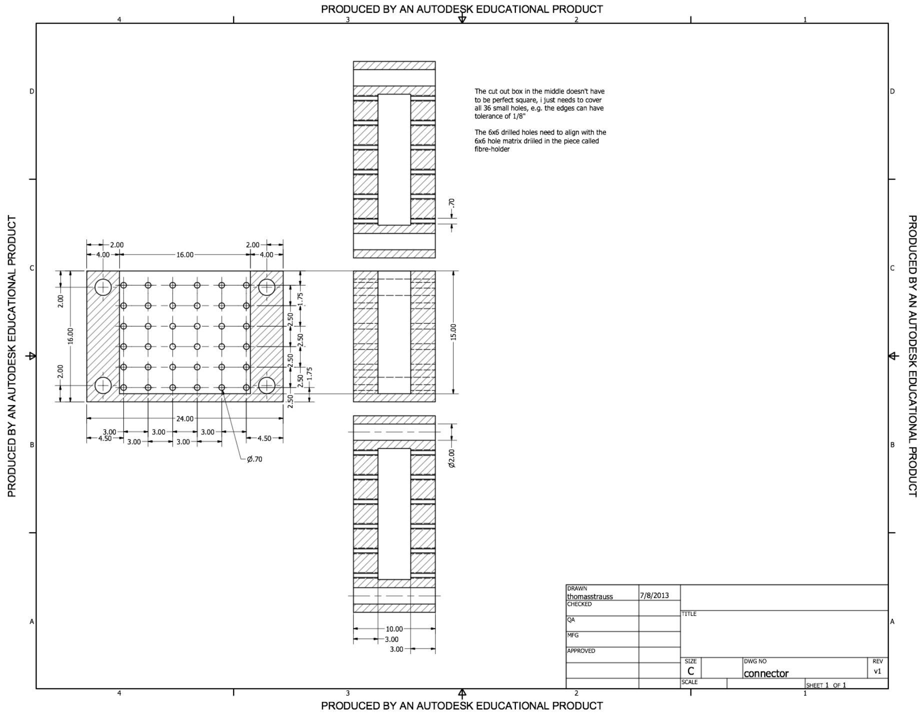


Figure 25. InternalFiberConnector.

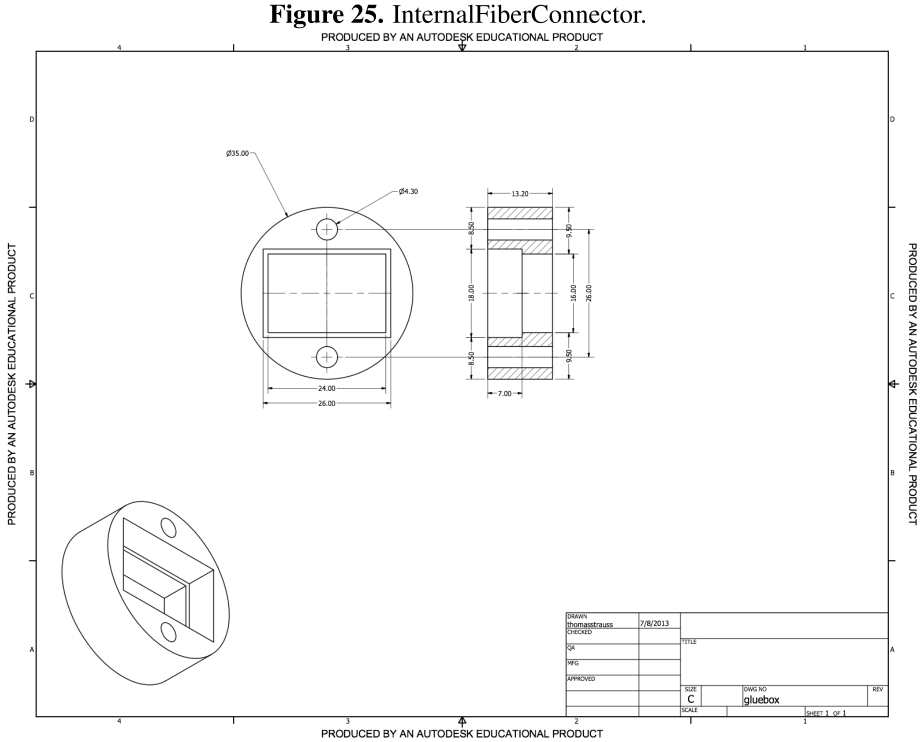


Figure 26. GlueBox.

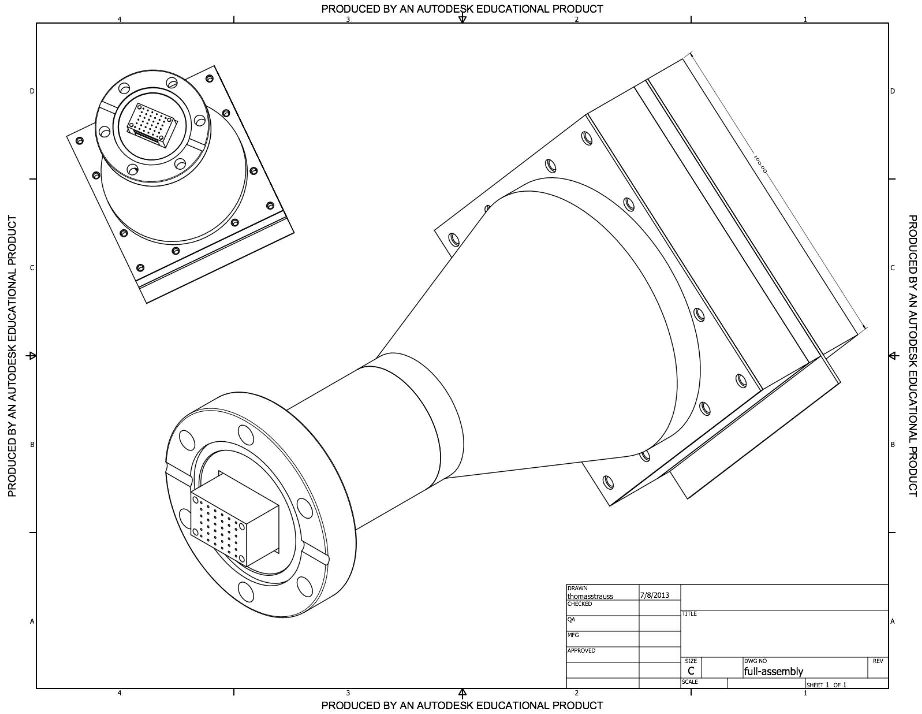


Figure 27. FullFeedthrough.

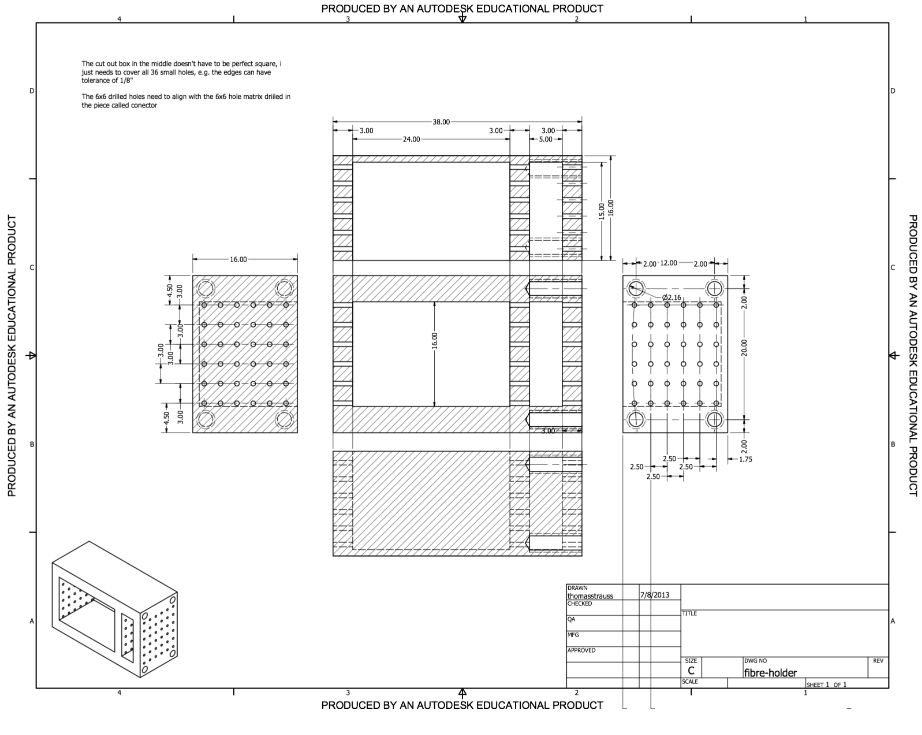


Figure 28. FiberHolder.

B. Electrical drawings of the circuit boards

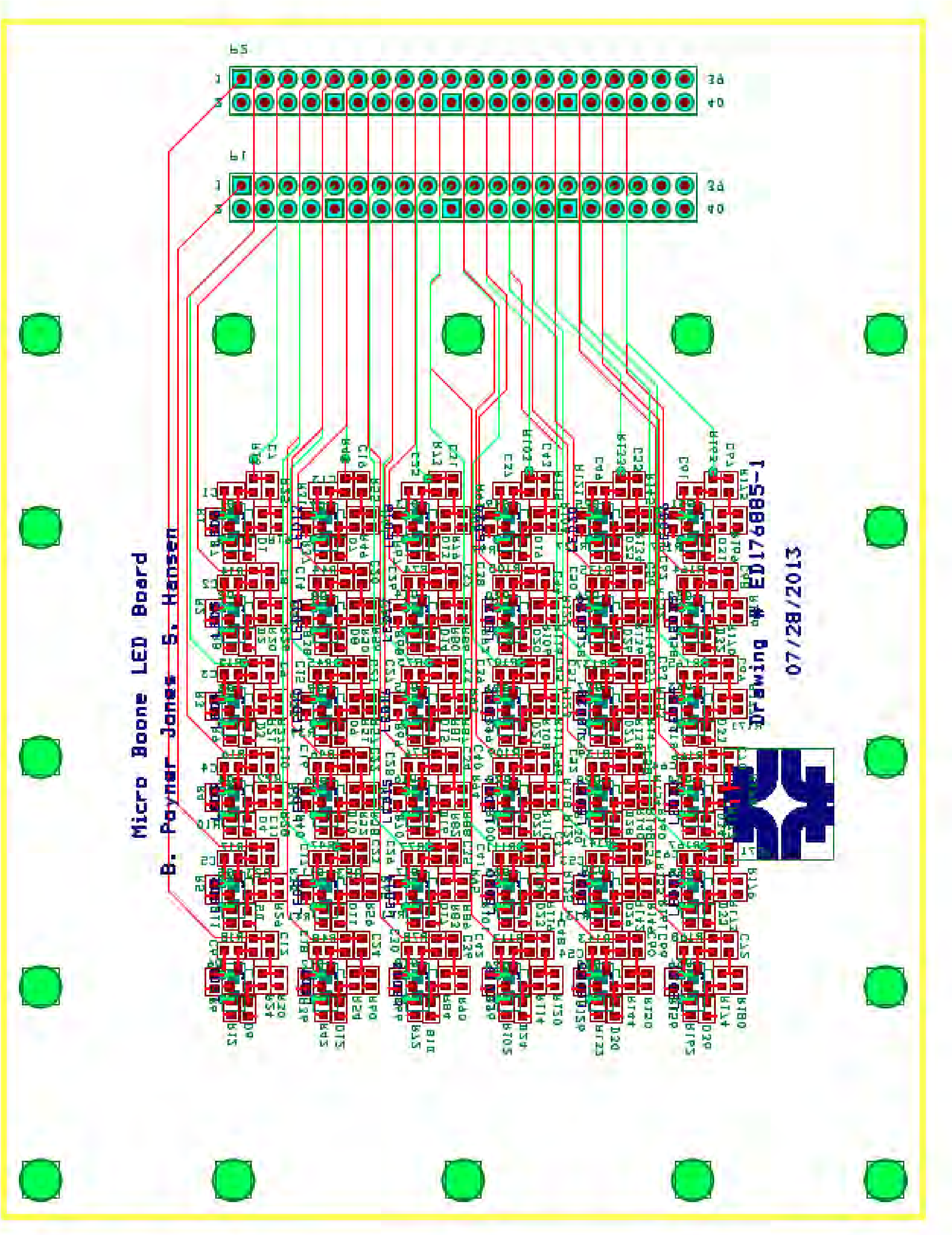


Figure 29. PCB print out of the LED board.

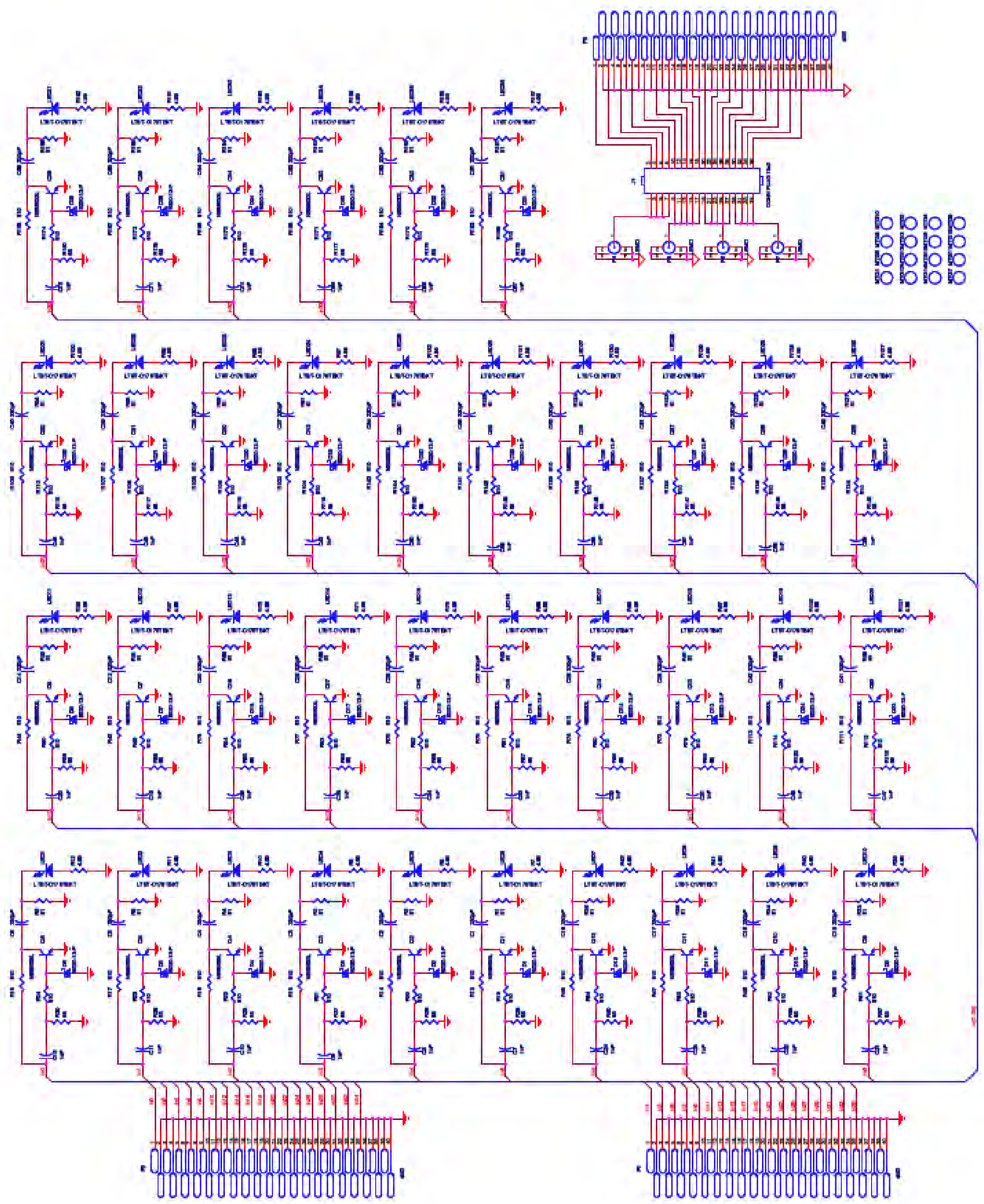


Figure 30. Schematic of the LED board.

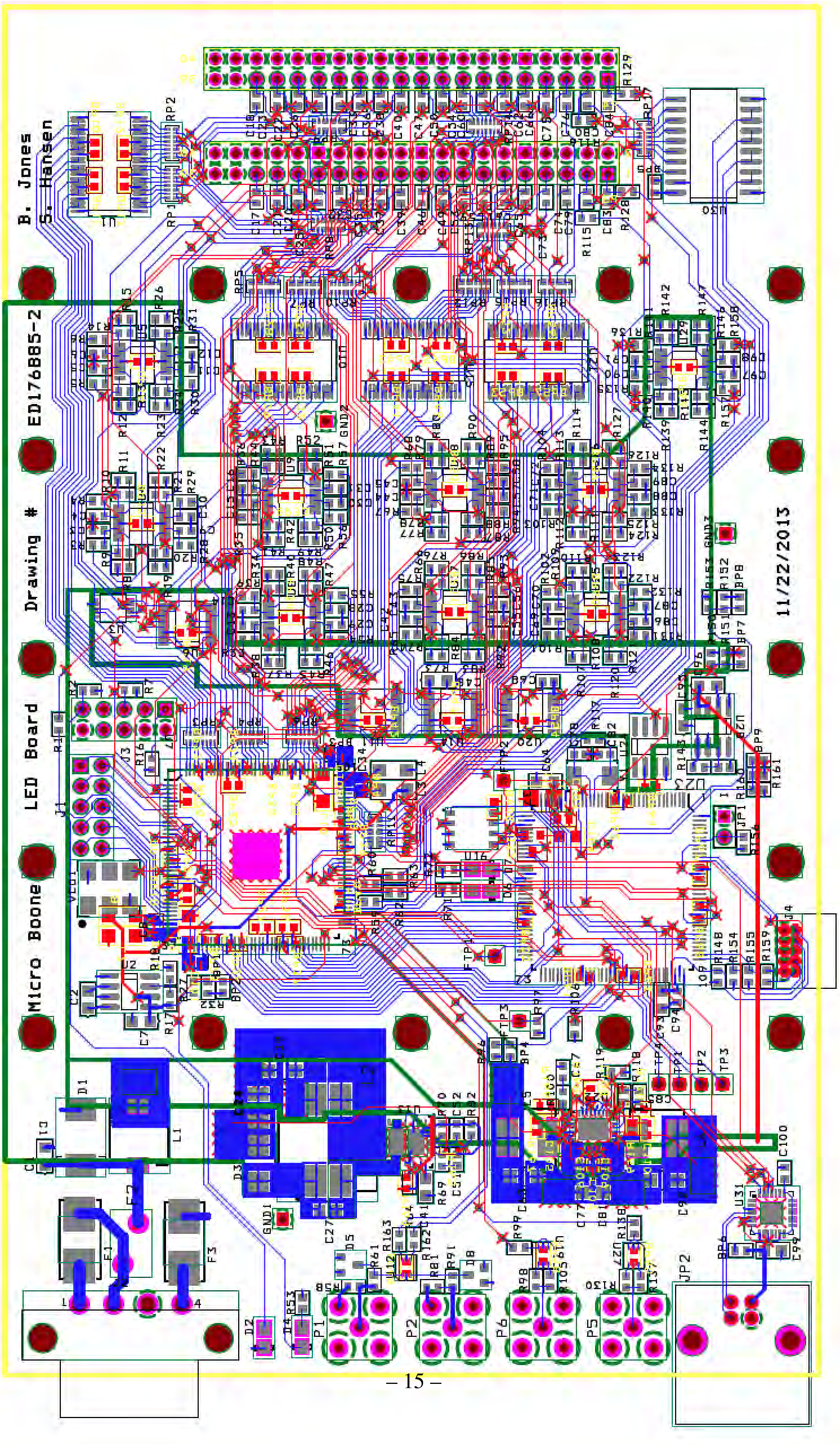


Figure 31. PCB print out of the Driver board..

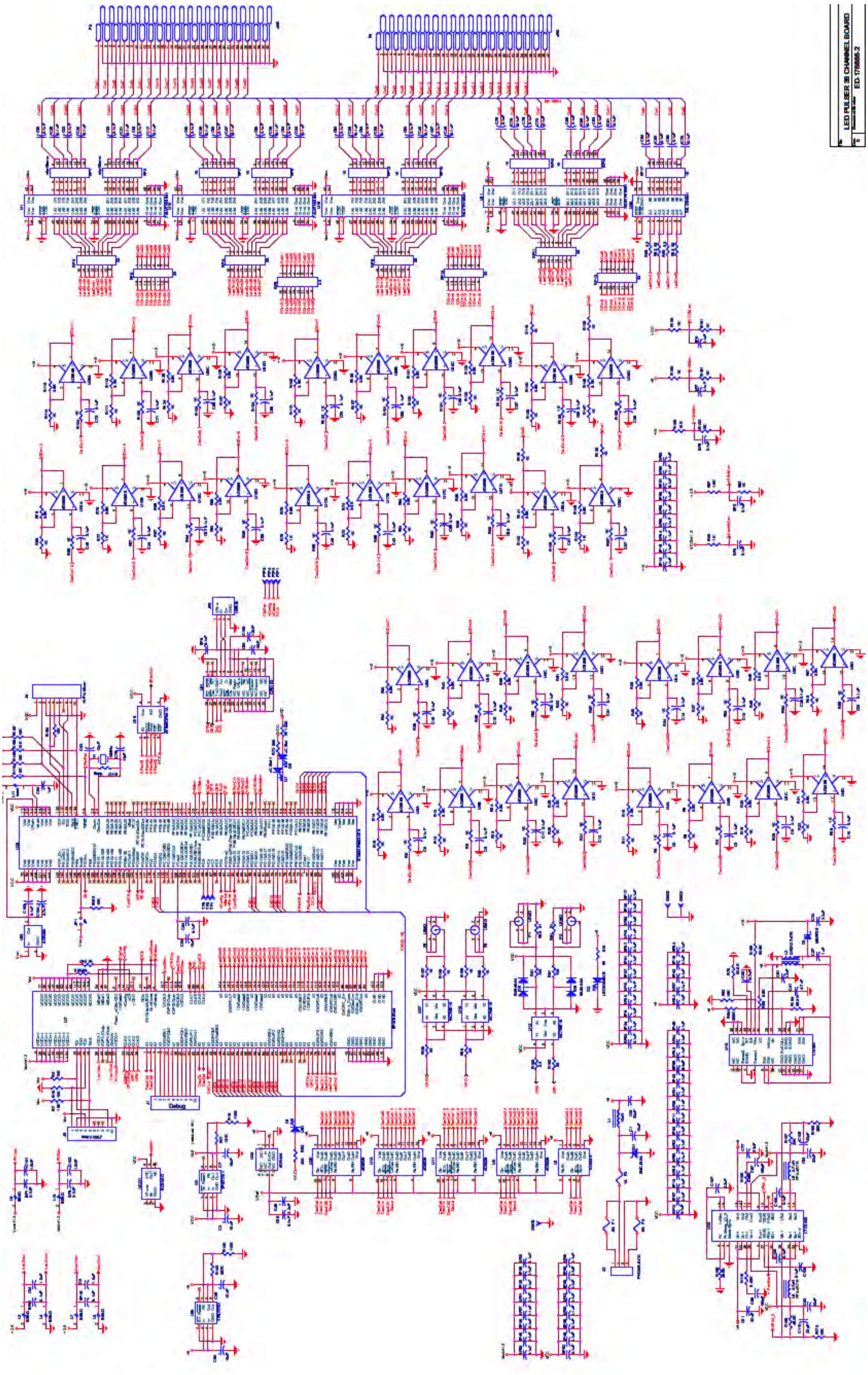


Figure 32. Schematic of the Driver board.